Modeling surface radio refractivity in Ulaanbaatar, Mongolia

Jamiyan Sukhbaatar, Nyamjav Jambaljav
Department of Electronics and Communication Technology
The National University of Mongolia
Ulaanbaatar, Mongolia
jamiyan@num.edu.mn, nyamjav@num.edu.mn

***Abstract*—This paper presents a hybrid model for surface radio refractivity. This model is a combination of deterministic and probabilistic models. The deterministic model represents regular changes in refractivity and the probabilistic model indicates random variations in the regular behavior. The both model parts determined in the seasonal and the diurnal cycles.**

I. Introduction

The radio refractive index is explained directly by electrical properties of molecules of air components, on the other hand, it is well expressed indirectly by “non-electrical” meteorological parameters of air - temperature, pressure and humidity. Therefore the index of refraction of the atmosphere changes with different altitudes and weather conditions making atmosphere as nonhomogeneous propagation media. The equation for refractive index, n, is obtained using the expression $n = \sqrt{\mu\varepsilon}$, where ε is the permittivity and μ, the permeability, may be assumed to be approximately unity for air [1]. The refractive index of air n is only slightly larger than unity (number of the order of 1.0003). Therefore, a more convenient radio refractivity N (N-units) is usually used:

$$N = (\mathrm{n}-1)\times 10^6 \qquad (1)$$

The refractivity is often estimated by meteorological parameters of air using the well-known refractivity formula [2].

This paper presents a surface refractivity model in Ulaanbaatar, Mongolia. Since the meteorological parametric values vary diurnally and also seasonally, the model for radio refractivity should reflect these cycles of variation. The proposed model is a hybrid model as a combination of deterministic (regular) and probabilistic (stochastic) models. The deterministic model represents the regular changes of refractivity namely seasonal and diurnal cycles. The probabilistic model presents random variations in regular behavior.

II. Methodology

Our proposed model is a hybrid model:

$$N = \langle N \rangle + \lambda \qquad (2)$$

where $\langle N \rangle$ is the deterministic model part and λ is the probabilistic or stochastic model part.

Two criteria considered to find the best deterministic models. First of all, the model should achieve a good fit to the general behavior of seasonal and diurnal variations of refractivity. To fulfill this criteria, the model should fit graphically to the regular refractivity values. Secondly, the model should have less model parameters. As a result, the model will be simple and easy to interpret.

The deterministic models found from regular or average values of seasonal and diurnal variations of refractivity. If the regular refractivity values removed, the random values of variations will remain. The probabilistic models found from these random values. The deterministic models will state a general regularity of refractivity for different seasons and hours. In addition, the probabilistic models will tell a randomness of the refractivity for the different periods.

In the case of deterministic models for seasonal and diurnal variations, both seasonal and diurnal meteorological parameters change periodically, the candidate mathematical model is Fourier series. The general refractivity deterministic model can be divided into two sub models. One represents seasonal variations and the other characterized diurnal variations.

III. Results

We have studied eight years (2009-2016) of refractivity in Ulaanbaatar, Mongolia because during this period meteorological measurements were taken in every 30 minutes. The data were obtained from the CWOP [3]. Fig. 1 (a) depicts all refractivity values in eight years. These refractivity values include seasonal and diurnal variations. Since we had planned to model seasonal and diurnal cycles independently, we separated these two variations.

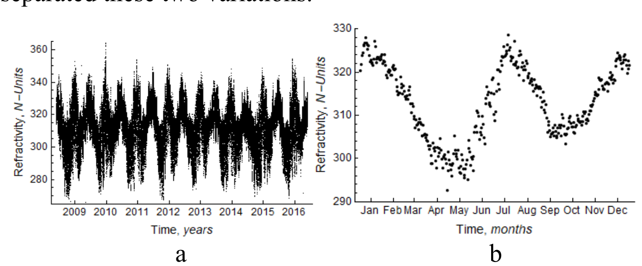

Fig. 1. (a) Eight year refractivity values, (b) daily average refractivity values.

A.1 Seasonal deterministic model

Firstly, we studied seasonal variations. To neglect diurnal variations, diurnal values were averaged. As the result, we have 365 values per year. We also averaged by years. The Fig. 1 (b) shows the seasonal refractivity values of the average year. A deterministic model was calculated from these data. We have tested the candidate mathematical models by two criteria (good fit graphically and less number of parameters). As the result, Fourier series with three terms representation sorted out. Fig. 2 illustrates the selected deterministic model and the seasonal variations in Ulaanbaatar.

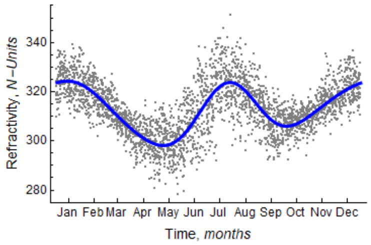

Fig. 2. The seasonal deterministic model. The solid line is the seasonal deterministic model and the dots are the seasonal variations.

Also, statistics of fitting are investigated. We examined the sum of squares error (SSE), R-square and Root mean squared error (RMSE) to choose the model. However graphical measures are more beneficial than statistical measures because they allow us to view the entire data set at once, and they can easily display a wide range of relationships between the model and the data. Finally, the seasonal deterministic model for Ulaanbaatar is:

$$y = a_0 + \sum_{i=1}^{3} a_i \cos(i\omega x) + b_i \cos(i\omega x) \qquad (3)$$

The model parameters are listed in Table I.

A.2 Seasonal probabilistic model

If the regular refractivity values removed, the random values of variations will remain. The proposed probabilistic model found from histogram of these random values. The seasonal deterministic model represents regular refractive values which neglected diurnal variations. To estimate a probabilistic model, each value (365 values each one for one day) of the deterministic model subtracted from the each year's diurnal average value. The remaining values are random refractivity values (Fig. 3 (left)).

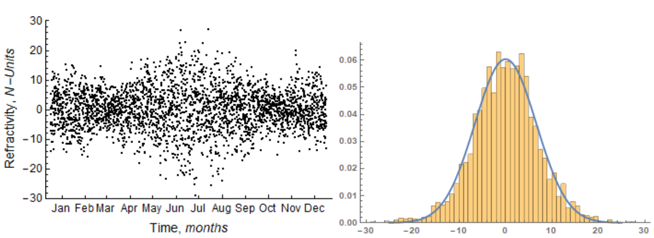

Fig. 3. Seasonal random values (left) and Histogram of seasonal random values and the PDF of the Normal distribution (right).

Histogram of the remaining values suggests us to use the normal distribution to describe their random behavior. The PDF of the Normal distribution ($\mu \rightarrow 0.049, \sigma \rightarrow 6.937$) is shown in Fig 3 (right).

B.1 Diurnal deterministic model

The seasonal deterministic model gives us 365 refractivity values which represents average refractivity values of all days of a year. Our original data are 48 measurements in a day. Thus, each value of 365 values subtracted from the each 48 refractivity values of a day. As the result, seasonal variations were removed and only diurnal variations were left.

For the diurnal deterministic model, we have used the same approach with the seasonal model. Both models were estimated by Fourier series with three harmonics**.** The diurnal model values of refractivity (solid line) and the diurnal variations (dots) are shown in Fig. 4 (a).

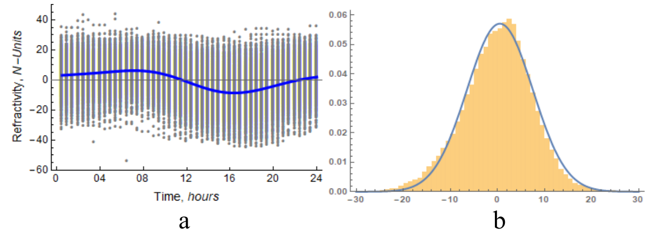

Fig. 4. (a) The diurnal deterministic model. The solid line is the Fourier model and the dots are the hourly variations, (b) Histogram of diurnal random values and the PDF of the Logistic distribution.

B.2 Diurnal probabilistic model

Diurnal regular values were removed from the diurnal variations. The probabilistic model was fitted by Logistic distribution. Histogram of diurnal random values and the PDF of the corresponding distributions are shown in Fig. 4 (b).

C. Summary

The brief summary of the hybrid model parameters in Ulaanbaatar is shown in Table 1 and Table 2.

TABLE I. THE DETERMINISTIC MODEL PARAMETERS

Variations	**Model name**	**Deterministic model parameters**							
		ω	a_0	a_1	b_1	a_2	b_2	a_3	b_3
Seasonal	Fourier series	0.0175	312.7	4.134	-3.139	6.67	7.466	-0.3186	-2.395
Diurnal	Fourier series	0.1304	0.0614	2.836	6.1476	0.339	-1.751	0.1662	-0.7279

TABLE II. THE PROBABILISTIC MODEL PARAMETERS

Variations	**Distribution**	**Probabilistic model parameters**	
		μ	σ
Seasonal	Normal	0.016	6.61
Diurnal	Logistic	0.303	4.8406

REFERENCES

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[3] Citizen Weather Observer Program, CWOP Database. [Online]. Available: www.wxqa.com.